FC (12)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Note No. 79	2. GOVT ACCESSION NO. (14) TN-79	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) TCP Resynchronization.		5. TYPE OF REPORT & PERIOD COVERED (9) Technical Note
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Vinton G. Cerf		8. CONTRACT OR GRANT NUMBER(s) (15) MDA903-76C-0093, ARPA Order -2494
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford Electronics Laboratories Stanford University Stanford, CA 94305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6T10 (11) 11 Jan 76
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency Information Processing Techniques Office 1400 Wilson Ave., Arlington, VA 22209		12. REPORT DATE 1/11/76 13. NO. OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS (if diff. from Controlling Office) Mr. Philip Surra, Resident Representative Office of Naval Research Durand 165, Stanford University		15. SECURITY CLASS. (of this report) UNCLASSIFIED (12) 12p. 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this report)

Reproduction in whole or in part is permitted for any purpose of the U. S. Government "A"

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Communication, synchronization, concurrency, protocols, duplicate detection, internetwork protocols, sequencing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This note elaborates the notion of duplicate detection through sequencing and the need for resynchronizing the sequence numbers in use on a full duplex connection under certain conditions.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TCP RESYNCHRONIZATION

by

Vinton G. Cerf

January 11, 1976

Technical Note #79

DIGITAL SYSTEMS LABORATORY
Dept. of Electrical Engineering Dept. of Computer Science
Stanford University
Stanford, California

This research was supported by the Defense Advanced Research Projects Agency under ARPA Order No. 2494, Contract No. MDA903-76C-0093

DSL Technical Note #79

TCP RESYNCHRONIZATION

Vinton G. Cerf
January 11, 1976

Introduction

The basic sequence numbering strategy employed in the ARPA Internet Transmission Control Program (TCP) is to assign (implicitly) a sequence number to each octet (8 bit unit) of text transmitted in an internet packet. [1,2] As explained in Tomlinson and amplified by Dalal [3,4], the finiteness of the available sequence number space requires that after a time, sequence numbers must be re-used. Care must be taken that the available sequence number space not be used up so fast that some packets carrying old sequence numbers are still in the network when these numbers are re-used. To assure this, we assume that packets can only remain in the network for a certain maximum lifetime. The maximum rate at which sequence numbers are used is related to this lifetime and to the size of the sequence number space. If the lifetime is T seconds and the maximum bandwidth (rate of sequence number consumption) is B, octets/second and the size of the sequence space is S octets, then we must have (see [2])

$$S > 2 \cdot B \cdot T \qquad (1)$$

Indeed, it may happen that T is really a random variable without a guaranteed maximum, in which case, reliability can be improved by writing

$$S = K \cdot B \cdot T \qquad (2)$$

which, for sufficiently large K makes the probability nearly zero that two packets carrying different text are assigned the same or overlapping sequence numbers. We have chosen the following parameters for the initial internet experiments:

$S = 2^{32}$ octets = sequence number space

$B = 2^{18}$ octets/sec (≈ 2 mbits/second) = bandwidth

$T = 2^{5}$ seconds ($\approx 1/2$ minute) = lifetime

STEP = 1 second (= 2^{18} octets)

We can compute the minimum cycle time as

$$C = S/B = 2^{14} \text{ sec } (\approx 4.55 \text{ hours}) \tag{3}$$

Combining (3) and (2), we obtain

$$K = \frac{S \text{ octets}}{B \cdot T \text{ octets}} = \frac{2^{32}}{2^{18} \cdot 2^{5}} = 2^{9} = 512 \tag{4}$$

Even if T is not bounded by 2^5 seconds, we can survive

$T \le 2^8 \cdot 2^5$ seconds = 8192 seconds = 2.27 hours

Resynchronization

Tomlinson introduces the need to select an initial sequence number (ISN) [3] using some well-known, periodic value, such as the time of day. Figure 1 plots the ISN value against time, where time and ISN are measured in the same units (e.g. using B as a parameter).

The same sequence number cannot be used to start each a connection, since this might introduce unintentional duplicate sequence numbers. We cannot rely on remembering the last sequence number used on a given connection, since this information may have been lost (e.g. host failure). Even during

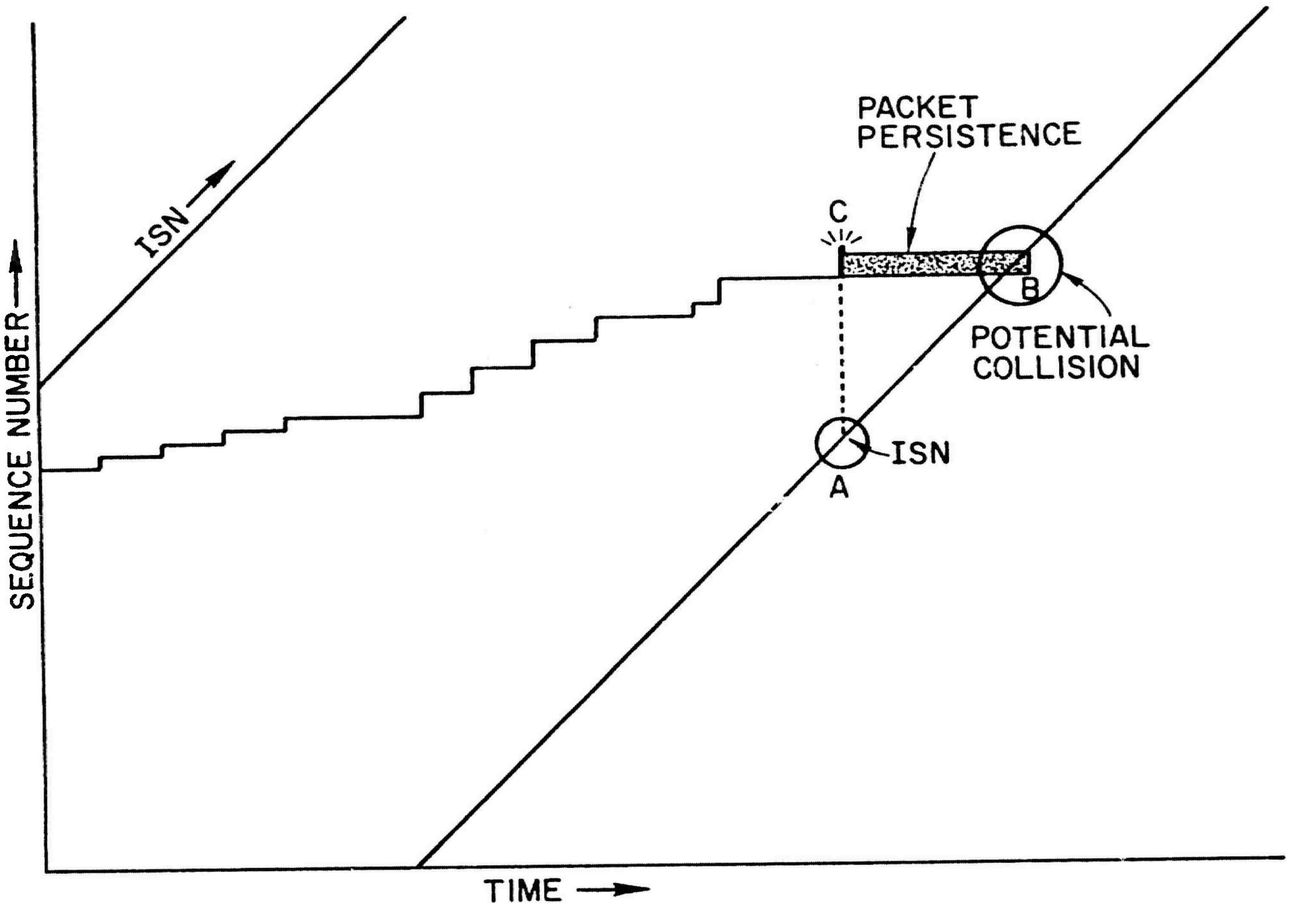

Figure 1

The Need for Resynchronization

the course of a particular connection, it may become necessary to resynchronize sequence numbers to avoid potential failures. In figure 1, we show the history of sequence numbers used by a particular connection. The lines labeled "ISN" represent the maximum permitted rate at which sequence numbers can be used. Suppose that the TCP supporting the connection fails at "C" and must be restarted. Assume, also, that the sequence number selected to restart is drawn from the value of ISN at the time event "C" occurred. The shaded area between "C" and "B" represents the maximum expected time that packets emitted at "C" can stay in the net. Clearly, the ISN line intersects this shaded area, indicating that, after the restart, it is possible that packets emitted at "C" may become undistinguishable from those potentially emitted along the ISN curve. To correct this flaw, the sequence number currently to be used on the connection must be resynchronized before running into the forbidden zone to the left of the ISN line.

Testing for the Need to Resynchronize

As packets are produced and sequence numbers assigned to them, the TCP must check for two possible conditions which indicate that resynchronization is needed. The first is that sequence numbers are being used up so fast that they advance faster than ISN. The other is that they advance so slowly that ISN "catches up with them."

The basic method of selecting an initial sequence number is to delay for an arbitrary period labelled a "clock tick" and then select the new ISN. In the TCP implementation, this amounts to one second of time during which up to 2^{18} octets may be transmitted. In figure 2, three sequence number histories are traced, ending in points "A", "B", and "C". In the

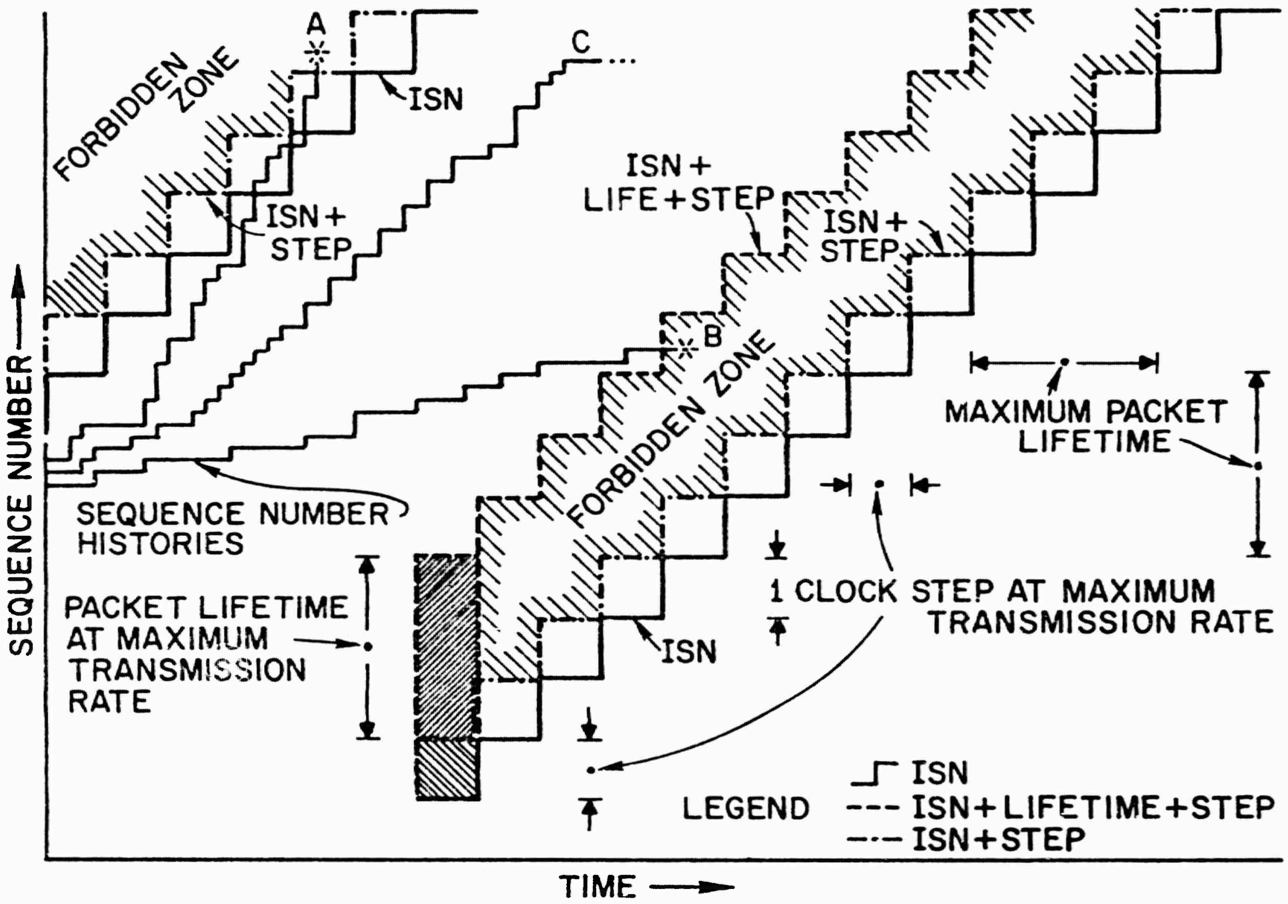

Figure 2

Detecting the Forbidden Zone

trace labelled "A," sequence numbers are used at such a rate that point "A" lies beyond ISN plus one step (clock tick). If the connection were to fail and be restarted at "A," the new ISN would be just below point "A" and would introduce potential unwanted duplicates.

This situation can be detected before transmission of the packet. Let SEQ represent the proposed sequence number of the packet, and SEQ+L-1 be the sequence number implicitly associated with the last octet of packet data. if ISN+STEP (at the moment that SEQ is to be assigned) lies in the range [SEQ, SEQ+L-1], then the type "A" ISN failure is about to occur. The solution is to send only as much text as is allowed (which does not result in the failure) and <u>wait</u> for the clock to tick again.

The situation in curve "B" is quite different. In this case, the connection is using sequence numbers so slowly that the forbidden zone preceding the ISN curve has advanced and run into the connection sequence number curve. There are two solutions. One is to wait for the packet lifetime plus one clock step to expire (in which case, the sequence history will pop out of the forbidden zone again. The other is to actively resynchronize the connection. The test for the type "B" situation is whether sequence number SEQ lies in the range [ISN, ISN+T+STEP] or [ISN, ISN+$33 \cdot 2^{18}$].

Note that all tests for inclusion must be modulo $S(2^{32})$ to account for the wraparound of sequence numbers.

Curve "C" in figure 2 shows a sequence number trace which tends, on the average, to lie within legal values at all times.

Conclusions

The value of clock step may be arbitrarily small, depending on the desired delay overhead to wait for the tick.

Checking for resynchronization is simple:

if SEQ ϵ [ISN, ISN+T+STEP] then resynchronize.

if ISN+STEP ϵ [SEQ, SEQ+L-1] (where L = packet length in octets)
then wait for clock to tick.

Appendix A - Window Size

There is a relationship between window size and the other quantities discussed in this paper. Let us call the average round-trip delay in the network D (measured so as to include the delay at the destination for accepting a packet and producing an acknowledgment). Maximum bandwidth cannot be achieved in this system unless the source is permitted to transmit continusously until receiving an acknowledgment. This leads to the relationship

$$W \geq B\ D = 2^{18}\ \text{octets/second} \cdot D\ \text{second} \qquad (5)$$

However, we have arbitrarily limited W to 2^{16} octets, which means that D must be bounded

$$D \leq \frac{2^{16}}{2^{18}}\ \text{seconds} = .250\ \text{seconds} \qquad (6)$$

This is not unrealistic for a ground based network, but is inadequate for a satellite-based network where $D > .5$ sec (the result of a minimum 89,600 mile round-trip in space: 89,600/186,200 = .48 seconds).

In the Arpanet, the average line capacity is 50 kbit/sec, of which only about 48kbit/sec or 6k octets/sec are available to the host/host protocol. Since W measures permission to transmit data, we can further reduce effective bandwidth by a minimum overhead. The TCP header length is currently 40 octets (32 are defined in reference 1; 4 more are needed for the ARPANET leader, and 4 more are currently used for a timestamp). In the best case, an ARPANET message can be 8096 bits (1012 octets) including leader, so the overhead factor is 40/1012 = 4%.

Using 5.76 k octets/sec for B in equation 5 we obtain

$$W \geq 5.76 \text{ k octets/sec} \cdot D \tag{5}$$

and, since $W = 2^{16}$ octets,

$$D \leq 2^{16}/5{,}760 \text{ sec} = 11.4 \text{ sec} \tag{6}$$

This compares favorably with measured ARPANET delays which average less than 0.5 seconds [7].

References

1. Cerf, V., Y. Dalal, C. Sunshine, "Specification of Internet Transmission Control Program," INWG General Note #72, December 1974 (revised).

2. Cerf, V. and R. Kahn, "A Protocol for Packet Network Intercommunication," IEEE Transactions on Communication, Vol COM-20, No. 5, May 1974.

3. Tomlinson, R., "Selecting Sequence Numbers," INWG Protocol Note #2, September 1974.

4. Dalal, Y. "More on Selecting Sequence Numbers," INWG Protocol Note #4, October 1974.

5. Belsres, D., "On Single Message Communication," INWG Protocol Note #3, September 1974.

6. Retz, D. and V. Cerf, "Station-Packet Radio Protocol," PRTN #160 December 19, 1975.

7. Kleinrock, L. and W. Naylor, "On Measured Behavior of the ARPANET," Network Measurement Note #18, NIC #20793, February 1974.

8. Kleinrock, L., W. E. Naylor, H. Opderbeck, "A Study of Line Overhead in the ARPANET," CACM, Vol. 19, No. 1, January 1976, pp. 3-13.

DISTRIBUTION

ARPA

Director (2 copies)
ATTN: Program Management
Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

ARPA/IPT
1400 Wilson Boulevard
Arlington, VA 22209

Dr. Robert Kahn
Mr. Steven Walker

Bell Laboratories

Dr. Elliot N. Pinson, Head
Computer Systems Research Dept.
Bell Laboratories
600 Mountain Avenue
Murray Hill, New Jersey 07974

Dr. Samuel P. Morgan, Director
Computing Science Research
Bell Laboratories
610 Mountain Avenue
Murray Hill, New Jersey 07974

Dr. C. S. Roberts, Head
The Interactive Computer Systems
Research Department
Bell Laboratories
Holmdel, New Jersey 07733

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

Mr. Jerry D. Burchfiel
Mr. R. Clements
Mr. A. McKenzie
Mr. J. McQuillan
Mr. R. Tomlinson
Mr. D. Walden

Burroughs Corporation

Dr. Wayne T. Wilner, Manager
Burroughs Corporation
3978 Sorrento Valley Boulevard
San Diego, CA 92121

Mr. David H. Dahm
Burroughs Corporation
Burroughs Place
P. O. Box 418
Detroit, MI 48232

Mr. B. A. Creech, Manager
New Product Development
Burroughs Corporation
460 Sierra Madre Villa
Pasadena, CA 91109

Cabledata Associates

Mr. Paul Baran
Cabledata Associates, Inc.
701 Welch Road
Palo Alto, CA 94304

California, University - Irvine

Prof. David J. Farber
University of California
Irvine, CA 92664

California, University - Los Angeles

Professor Gerald Estrin
Computer Sciences Department
School of Engineering and Applied Science
Los Angeles, CA 90024

Professor Leonard Kleinrock
University of California
3732 Boelter Hall
Los Angeles, CA 90024

Mr. William E. Naylor
University of California
3804-D Boelter Hall
Los Angeles, CA 90024

Collins Radio Group
1200 N. Alma Road
Richardson, Texas 75080

Mr. Don Heaton
Mr. Frederic Weigl

Defense Communications Engineering Center

Dr. Harry Helm
DCEC, R-520
1860 Wiehle Avenue
Reston, VA 222090

General Electric

Dr. Richard L. Shuey
General Electric Research and Development Center
P. O. Box 8
Schenectady, New York 12301

Dr. A. Bell Isle
General Electric Company
Electronics Laboratory
Electronics Park
Syracuse, New York 13201

Mr. Ronald S. Taylor
General Electric Company
175 Curtner Avenue
San Jose, CA 95125

General Motors Corporation
Computer Science Department
General Motors Research Laboratories
General Motors Technical Center
Warren, MI 48090

Dr. George C. Dodd, Assistant Head
Mr. Fred Krull, Supervisory Research Engineer
Mr. John Boyse, Associate Senior Research Engineer

Hawaii, University of
The ALOHA System
2540 Dole Street, Holmes 486
Honolulu, Hawaii 96822

Professor Norman Abramson

Hughes Aircraft Company

Mr. Knut S. Kongelbeck, Staff Engr.
Hughes Aircraft Company
8430 Fallbrook Avenue
Canoga Park, CA 91304

Mr. Allan J. Stone
Hughes Aircraft Corporation
Bldg. 150 M.S. A 222
P. O. Box 90515
Los Angeles, CA 90009

Hughes Aircraft Company
Attn: B. W. Campbell 6/E110
Company Technical Document Center
Centinela and Teale Streets
Culver City, CA 90230

IBM

Dr. Patrick Mantey, Manager
User Oriented Systems
International Business Machines Corp.
K54-282, Monterey and Cottle Roads
San Jose, CA 95193

Dr. Leonard Y. Liu, Manager
Computer Science
International Business Machines Corp.
K51-282, Monterey and Cottle Roads
San Jose, CA 95193

Mr. Harry Reinstein
International Business Machines Corp.
1501 California Avenue
Palo Alto, Ca 94303

Illinois, University of

Mr. John D. Day
University of Illinois
Center for Advanced Computation
114 Advanced Computation Bldg.
Urbana, Illinois 61801

Institut de Recherches d'Informatique et d'Automatique (IRIA)
Reseau Cyclades
78150 Rocquencourt
France

Mr. Louis Pouzin
Mr. Hubert Zimmerman

Information Sciences Institute,
University of Southern California
4676 Admiralty Way
Marina Del Rey, CA 90291

Dr. Marty J. Cohen
Mr. Steven D. Crocker
Dr. Steve Kimbleton
Mr. Keith Uncapher

London, University College

Professor Peter Kirstein
UCL
Department of Statistics &
Computer Science
43 Gordon Square
London WC1H OPD, England

Massachusetts Institute of Technology

Dr. J. C. R. Licklider
MIT
Project MAC - PTD
545 Technology Square
Cambridge, Massachusetts 02139

MITRE Corporation

Mr. Michael A. Padlipsky
MITRE Corporation
1820 Dolly Madison Blvd.
Westgate Research Park
McLean, VA 22101

Network Analysis Corporation
Beechwood, Old Tappan Road
Glen Cove, New York 11542

Mr. Wushow Chou
Mr. Frank Howard

National Bureau of Standards

Mr. Robert P. Blanc
National Bureau of Standards
Institute for Computer Sciences
and Technology
Washington, D. C. 20234

Mr. Ira W. Cotton
National Bureau of Standards
Building 225, Room B216
Washington, D. C. 20234

National Physical Laboratory
Computer Science Division
Teddington, Middlesex, England

Mr. Derek Barber
Dr. Donald Davies
Mr. Roger Scantlebury
Mr. P. Wilkinson

National Security Agency
9800 Savage Road
Ft. Meade, MD 20755

Mr. Dan Edwards
Mr. Ray McFarland

Norwegian Defense Research Establishment
P. O. Box 25
2007 Kjeller, Norway

Mr. Yngvar G. Lundh
Mr. P. Spilling

Oslo, University of

Prof. Dag Belsnes
EDB-Sentret, University of Oslo
Postbox 1059
Blindern, Oslo 3, Norway

Rand Corporation
1700 Main Street
Santa Monica, CA 90406

Mr. S. Gaines
Mr. Carl Sunshine

Rennes, University of

M. Gerard LeLann
Reseau CYCLADES
U.E.R. d'Informatique
B. P. 25A
35031-Rennes-Cedex, France

Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, CA 94025

Ms. E. J. Feinler
Augmentation Research Center

Dr. Jon Postel
Augmentation Research Center

Mr. D. Nielson Director
Telecommunication Sciences Center

Dr. David Retz
Telecommunication Sciences Center

System Development Corporation

Dr. G. D. Cole
System Development Corporation
2500 Colorado Avenue
Santa Monica, CA 90406

Telenet Communications, Inc.
1666 K Street, NW
Washington, D. C. 20006

Dr. Holger Opderbeck
Dr. Lawrence G. Roberts
Dr. Barry Wessler

Transaction Technology Inc.

Dr. Robert Metcalfe
Director of Technical Planning
Transaction Technology Inc.
10380 Wilshire Blvd.
Los Angeles, CA 90024

Defense Communication Agency

Dr. Franklin Kuo
4819 Reservoir Drive
Washington, D. C. 20007

Xerox Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

Mr. David Boggs
Dr. William R. Sutherland

STANFORD UNIVERSITY

Digital Systems Laboratory

Mr. Ronald Crane
Mr. Yogen Dalal
Ms. Judith Estrin
Professor Michael Flynn
Mr. Richard Karp
Mr. James Mathis
Mr. Darryl Rubin
Mr. Wayne Warren

Digital Systems Laboratory Distribution

Computer Science Department - 1 copy
Computer Science Library - 2 copies
Digital Systems Laboratory Library - 6 copies
Engineering Library - 2 copies
IEEE Computer Society Repository - 1 copy

Electrical Engineering

Dr. John Linvill